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The Availability and Resource Cost of Water for Coal Conversion

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THE AVAILABILITY AND RESOURCE COST OF WATER FOR COAL CONVERSION

State of Illinois
Bureau of the Budget
Office of Planning
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The Availability and Resource Cost of Water for Coal Conversion

INTRODUCTION

The U.S. has a large supply of coal reserves which could satisfy a significant portion of its growing energy needs. Currently, coal constitutes nearly 92% of the Nation's fossil fuel reserve by heat value, CENTRAL INTELLIGENCE AGENCY, (1977). There are two large pockets of coal in the U.S.; the Western states of Montana and Wyoming contain about 36% by tonnage and the Interior Region consisting of the states of Illinois, Indiana, and Kentucky contain about 23% of total demonstrated coal reserves.

Coal resources have had a declining role in the U.S. as an energy source. As recently as 1943, coal contributed more than 50% of the Nation's total energy needs. By 1977, only 18% of our Nation's energy needs were met by coal, U.S. BUREAU OF LAND MANAGEMENT, (1978). Oil and natural gas replaced coal in many energy consumption sectors. But, with ever growing energy requirements, there is little likelihood of supplying expected demand with domestic oil and natural gas. The U.S. is seeking to address the problem of domestic energy shortfall by expanding the use of coal as an energy resource. To expand the use of coal, the federal government has offered two programs. First, natural gas and oil consuming facilities are being encouraged to switch to coal. Second, new facilities are being planned and developed that will convert coal to substitutes for oil and gas. Given the nature of fuel consumption in the economy and the environmental impact of switching from natural gas and oil to coal, the success of the coal expansion project depends largely on the commercialization of new technologies that convert coal to clean gas and oil.

Two conversion technologies are coal liquefaction and coal gasification. Coal liquefaction is the conversion of solid coal to a liquid. The liquid derived from coal liquefaction could compete with petroleum refined products such as clean boiler

fuels suitable for electric power generation and as a substitute for high-grade fuels such as gasoline, heating oil, and chemical feedstock. Coal gasification is the chemical transformation of solid coal into a gas which is essentially methane mixed with carbon monoxide but virtually free of sulfur.

Plans to site coal conversion facilities are being discussed in both the West and Midwest. The comparative advantage of developing coal in a particular region depends on several factors such as: type of coal available, proximity to market of coal derivatives (including transportation costs), availability of other natural resources (including air, land and water), and environmental considerations, etc. This report investigates the comparative advantage of coal conversion in the West versus the Midwest from the point of view of water availability, develops a methodology to measure the resource cost of water, and reviews the literature on coal conversion siting in light of the methdology presented.

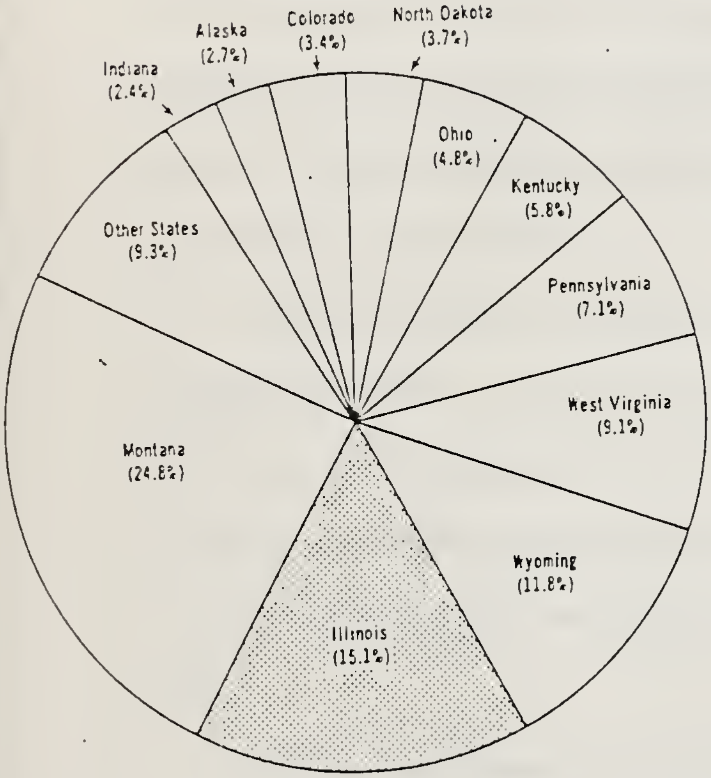
BACKGROUND - COAL

Illinois has the largest reserve of bituminous coal in the U.S. and ranks second in the amount of total recoverable reserves with 15% of the Nation's coal reserves by tonnage (Figure 1). Coal lies in 86 of the State's 102 counties. More than one-half of Illinois' coal mines are strip mines and all are located in the lower part of the State, WEIL AND GRANDYS (1976). Midwestern coal is almost entirely bituminous and anthracite coal, and has a higher heating value than most western coal (Figure 2). Western coal is predominately subbituminous and lignite.

Historically, western coal reserves have played a limited role in meeting energy-related needs in the Midwest. Demand for coal in the Midwest and in the East has largely been met by the substantial coal reserves in the Appalachian and midwestern coal mines. Production of coal in the West, however, has increased rapidly in the last few years. In 1967, 28 million tons were produced, but by 1977,

Figure 1

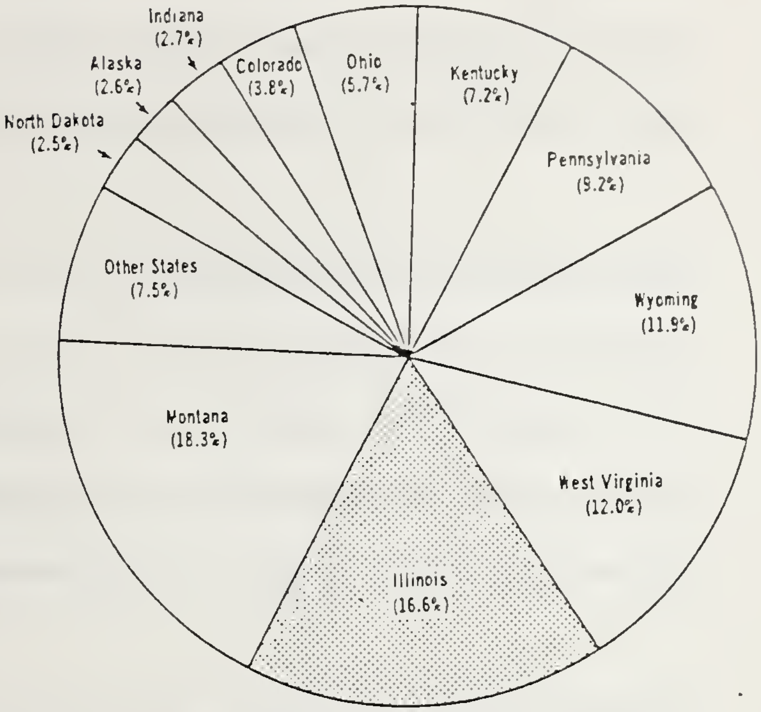
istribution of Demonstrated Coal Reserves
(by tonnage)



Total tonnage: 433,948 million short tons
(SMITH & STALL, 1975)

Figure 2

Distribution of Demonstrated Coal Reserves
(by heat value)



Total potential energy: 8,915,028 trillion BTU
(SMITH & STALL, 1975)

170 million tons were produced in the West, U.S. BUREAU OF LAND MANAGEMENT (1978). The increased reliance on western coal has come as a result of several related factors.

Coal has traditionally been the primary energy source in electric power generation in the Midwest. Oil and natural gas replaced many industrial uses of coal, but electric power generation has increasingly used coal as a major source of energy. And, since transportation is a significant portion of the overall cost of coal, midwestern power plants have relied on nearby Appalachian and midwestern coal resources. The economics of power generation were substantially changed by the 1970 Clean Air Act and its subsequent amendments, particularly with respect to sulfur dioxide emissions regulations. Use of high sulfur midwestern coal became

impossible unless utilities made capital investments in flue gas desulfurization systems (FGD). Western coal, however, in most situations, could be burned without the installation of FGD systems. The emission standards were low enough to eliminate the use of most Illinois coal, but high enough to permit the use of western coal. In spite of the increased transportation costs, utilities in the Midwest began to switch to western coal.

Coal consumption in Illinois was nearly 40 million tons in 1974, WEIL AND GRANDYS (1976). This represents 9% of total U.S. coal consumption. Only 64%, however, was domestic coal; the remainder was low-sulfur western coal. The western coal states have gained an increasing share of Illinois' coal market. From 1970 to 1976 western coal imports increased from 1.1 million tons to 11.1 million tons.

Recent amendments to the Clean Air Act have further reduced allowable sulfur dioxide emissions. Now, western coal as well as midwestern coal, will require at least a partial scrubbing and hence the use of FGD systems. The new emission standards will undoubtedly reduce the economic advantage of western coal. The midwestern and eastern regions will likely start utilizing more of the coal resources in their own region and the importation of western coal should recede. The current upward trend in western coal consumption, however, can be expected to continue for some time. The new emission standards do not go into effect until 1983 and they will apply only to new plants.

It is important to Illinois and to Illinois' coal miners that new and developing technologies that utilize coal in an efficient and environmentally acceptable manner be encouraged. But expanded coal production is not only a parochial issue. Expanded use of coal is now a national priority. Coal is seen as the vehicle to energy self-sufficiency in the near-term. Illinois coal can play a major role in

meeting energy needs in the future, particularly if commercialization of new technologies that convert coal to clean gas and oil is successful.

WATER RESOURCES AND ENERGY

The relationship between energy and water is a circular one. Energy is required to develop water resources, and water is needed for most energy production. A balance must be struck between development and use of these two resources.

Water and energy are sometimes required as joint inputs. Adequate water and energy are necessary for pumping water to irrigated fields. Water and energy can also be substituted for each other. Irrigation by gated pipe is more water intensive but less energy intensive than a center pivot irrigation system. Also, suboptimal allocation of one of these resources could give rise to misuse of the other. For example, it is generally felt that as a result of maintaining an artificially low price of natural gas the development of energy resources did not proceed in a desirable manner in the Texas High Plains and the ground water resources were exhausted at a rate faster than socially optimal.

Water also has unique characteristics as an economic commodity. Water is renewable and an average amount of precipitation can be expected over a given period of time. Water resources used as a flow concept cannot be depleted, though there certainly could be demand for water in excess of available supply at any given period of time.

Determining the value of a specific pool of water is very difficult. The value of water is the value of the marginal product in the first use, plus the value of the marginal product in the second use and so on. The water may be contaminated by a use so that it is not reusable without purification. If it is polluted and returned to a larger body, the quality of the source can be rendered unusable for a variety of

uses. The greater the demands placed on the water resource, the greater the consequent strain on water quality.

One characteristic of water that makes its worth difficult to determine is that it is cheap. Water is generally a free good whose only associated cost is the cost of extraction and distribution. This usually means that water supply and demand is handled on a local basis because the cost of shipping water from one place to another is generally astronomically high compared to the price generally paid for water.

WATER RESOURCES AND COAL CONVERSION

Coal conversion requires an abundant, dependable supply of water, both as a feedstock and for cooling purposes. Air cooling and extensive re-use of process water reduces the water requirement. Trade-offs must be evaluated between water usage and the capital investment costs of water treatment and air cooling equipment. The exact amount of water employed in a coal conversion facility varies widely depending on the technology used and hence water use estimates are generally presented as a range.

The Office of Coal Research, U.S. Department of Interior, as reported by SCHMETZ, et al. (1974) determined that the water requirements for a gasification plant with a capacity of 250 million standard cubic feet (scf) per day was between 11,489 acre feet per year and 49,001 acre feet per year. This is similar to the requirements used by HOGLUND AND ASBURY (1974).

A liquefaction plant producing 100,000 barrels a day (bbl/day) of synthetic crude oil would require an estimated 21,444 acre feet per year according to RALPH M. PARSONS CO. (1974). The U.S. Bureau of Mines determined that 17,000 acre feet per year is needed, see SCHMETZ, et al. (1974). The Office of Coal Research assumed a total water requirement of 20,000 acre feet per year for a 100,000

bbl/day fuel oil plant. THE WESTERN STATES WATER COUNCIL (1977) and WILLIAMS (1976) have estimated water requirements for a 100,000 bbl/day liquefaction plant between 20,000 acre feet and 130,000 acre feet. In this study, the estimate of RALPH PARSONS & CO. (1974) of 21,444 acre feet is used. The higher estimate of 130,000 acre feet per year is also included to reflect the upper limit of water requirements.

Water is one of the major inputs required in coal conversion processes. Its availability is of paramount importance in controlling the location and the pace of coal conversion projects. The availability of water is often seen as one of the major factors limiting the choice of sites for commercial size coal conversion plants. Beyond the availability of sufficient quantities of water in a given region, concern exists over water quality; institutional, legal and economic problems; as well as concerns from current water users.

In order to investigate the comparative advantage of coal conversion in the West versus the Midwest from the point of view of water resources, the following points are important:

- Cost of making water available to conversion plants. This cost includes cost of extraction of water but not the rent (payment) for water resources per se.
- Physical availability of water and the patterns of use in the West and the Midwest. This information will be useful in determining if sufficient water is available or if water will be diverted from other sectors.
- Water laws in the West and in the Midwest that could restrict the use of water for coal development projects.
- Estimate of the value of output per unit of water in coal conversion and in sectors from which water could be displaced by the development of coal conversion technologies.

The cost of making water available for coal conversion has already been studied by others, e.g. BRILL, et al. (1977a) and GIBBS (1976). These studies indicate water supply costs are an important component of the total cost of

production. BRILL, et al. (1977a) further determined that shipping water was an extreme solution to the problem of meeting water needs as demand for water was drastically reduced as the cost of water shipments increased. As a result, water availability should be determined on a regional or local basis.

The last three issues mentioned above are addressed in this report.

WATER AVAILABILITY AND USE

Illinois has 53,000 million gallons a day (mgd)[1] in ground and surface water resources (Table 1), ILLINOIS TECHNICAL ADVISORY COMMITTEE ON WATER RESOURCES (1967). Average annual rainfall in the southern coal-mining part of the State is 46 inches, well above the U.S. average of 30 inches per year. Withdrawals in the State are approximately 13,000 mgd or 25% of total available supply.

Table 1

OVERVIEW OF WATER AVAILABILITY IN ILLINOIS

WATER AVAILABILITY	(MGD)
Supply from Atmosphere	99,000
Evaporation and Transpiration	-76,000
Surface and Groundwater Flows	23,000
Water Available from Border Rivers and Lake Michigan	+30,000
Total Water Available	53,000

It is generally accepted that ground water resources in Illinois and in the western states are not adequate for supplying large quantities for uses such as coal conversion, see TRELEASE (1976), SEAY et al. (1972), ILLINOIS ENVIRONMENTAL PROTECTION AGENCY (1978) and BAUMANN AND DWORKIN (1978). Potential sources of ground water have been sited in Illinois specifically in the East St. Louis

area but the question of water availability for coal conversion basically hinges on the supply of and demand for surface water.

Information from Table 2 below shows that there is a comparatively larger supply of surface water in the Midwest than in the West.

Table 2

Comparison of Total Stream Flow and Consumptive Requirements in 1985 for the West and Midwest (mgd)

		Midwest[1]	West[2]
Total Stream Flow[3]	Average	194,910	85,084
	Low Flow	112,140	45,924
Consumptive Requirements[4]		3,916	25,721
As a % of Total Stream Flow			
	Average	2.0	30.2
	Low Flow	3.5	56.0

[1] Midwest includes the water flow in the Upper Mississippi and Ohio River Basins, containing the Eastern and Appalachian Coal Regions.

[2] West includes the water flow in the Missouri and Arkansas River Basins containing the Western Interior, Powder River, and Fort Union Coal Reserves.

[3] Total stream flow is an estimate of the flow that would be observed with evaporation, imports and exports continuing as at present. The low flow represents a condition that is likely to occur in 5 out of 100 time periods.

[4] Consumptive surface water requirement is the actual amount of water consumed in a year. During periods of below normal rainfall, irrigation demands could be greater thereby increasing consumptive requirements.

(U.S. BUREAU OF LAND MANAGEMENT, 1978)

Average total stream flow in the Midwest is 194,910 mgd compared to 85,084 mgd in the West. The ratio between the mean stream flow and the low flow is approximately 55% in both regions. Low flow conditions can be expected to occur in 5 out of 100 years (or months) and describe the lowest flow rate that can be expected. Consumptive requirements in the two regions vary substantially. In the West consumptive requirements are nearly 7 times greater than in the Midwest. Consumptive requirements as a percent of stream flow are 2% in the Midwest and

30% in the West under average flow conditions. During low flow conditions, the consumptive requirement as a percent of stream flow is 3% in the Midwest and 56% in the West.

Table 3 gives the highest and lowest calculated flow in the West and Midwest. Calculated flow is the difference between total stream flow and consumptive requirements. Projected figures of stream flow and consumptive use for the years 1985 and 2000 are given by the U.S. BUREAU OF LAND MANAGEMENT(1978). The 1985 and 2000 projections anticipate evaporations, exports and imports as currently exist with no major diversion for coal development, increased irrigation or other large water use project. In 1985, April's calculated flow is projected to be the highest of the year in the Midwest with 31,061 mgd and September is the lowest with 5,794 mgd. Positive flows do not assure water availability since availability is dependent on water quality, water law and minimum water level requirements.

In the West, a negative number is projected in August during low flow conditions in 1985. Demand for water during this month exceeds the supply by 45 mgd. By the year 2000 demand is expected to exceed supply during average flow conditions by 62 mgd and during low flow conditions by 587 mgd. The implication of demand exceeding supply as discussed in the section under water laws, is that those with more recent water rights would be allocated water resources only after those with older rights have received their full allocation.

Table 3

Comparison of Highest and Lowest
Monthly Calculated Flow[1] (mgd)

	Midwest		West	
1985	Average	Low Flow	Average	Low Flow
Highest Monthly Calculated Flow	31,061	19,135	9,167	2,741
Lowest Monthly Calculated Flow	5,794	3,186	480	-45
Ratio of Highest to Lowest Calculated Flow[2]	4.4	5.0	18.1	61.9

2000	Midwest		West	
	Average	Low Flow	Average	Low Flow
Highest Monthly Calculated Flow	30,883	18,957	9,167	2,741
Lowest Monthly Calculated Flow	5,687	1,709	-62	-587
Ratio of Highest to Lowest Calculated Flow[2]	4.4	10.1	148.9	5.7

[1] Calculated flow is the difference between total stream flow and the consumptive requirements for both average and low flow conditions. Negative flows indicate water shortages. Positive flows do not necessarily mean that water is available. Actual availability depends on water quality, water law and minimum in-stream requirements. Low flow represents lowest calculated flow that can be expected.

[2] Ratio is computed using the formula $\frac{/high-low/}{low}$

(Adapted from U.S. BUREAU OF LAND MANAGEMENT, 1978)

Table 3 also shows the magnitude of the difference between the maximum and minimum flow months by computing a ratio of the lowest and highest calculated flow for the year. A relatively low and stable ratio would indicate a dependable, predictable water situation with little variance. The ratio in the West between the high and the low calculated flow ranges from 5 to 148. The ratio in the Midwest is between 4 and 10. These figures point up the seasonal variations in the West and the stability of water flow in the Midwest. Further, they illustrate the water shortages that could exist in the West.

Examples of monthly and seasonal variations in the West are the Yellowstone River and the Colorado River. The average annual hydrograph for the Yellowstone River at Sidney, Montana shows drastic seasonal fluctuations and periods of low flow during the year when insufficient supply for coal conversion facilities may exist. The annual mean flow in the Yellowstone River at Sidney, Montana is 9,400,000 acre feet, but annual flows as low as 4,100,000 acre feet have been recorded, HANSEN (1976). These seasonal variations and large fluctuations from year to year could restrict the dependability of an adequate water supply.

The availability of water can only be evaluated in relation to the demand for water. The demand side for water illustrates the greatest difference between the Midwest and the West. The total amount of water demanded or required for a particular use is the amount earmarked for that purpose. The velocity of use of water is not infinite, i.e., water once earmarked for a specific use may not be available for competing uses at the same time. Some portion of the water required may also be degraded in quality and thus be unfit for certain productive uses. Thus, the total water requirements of a production process are important in determining water availability.

Table 4 gives the quantity withdrawn and the percentage withdrawn by major sector in 1975 for the three relevant states.

Table 4

Withdrawal (mgd) in 1975 and Percent of Water Use by Major Water-Using Sector[1]

	Illinois		Montana		Wyoming	
	mgd	%	mgd	%	mgd	%
*Public Supplies	2,100	16.0	130	1.1	56	.8
Rural use	60	.4	55	.5	29	.4
Irrigation	41	.3	11,000	96.0	6,800	94.2
Self-supplied Industrial	11,000	83.3	270	2.4	330	4.6
Total	13,201	100	11,455	100	7,215	100

[1] Data presented in this table include the States of Montana and Wyoming as they are the most likely sites for coal conversion in the West.

* Public supply: Water obtained from a water utility that serves the public. Includes domestic, commercial and industrial uses.

Rural: Includes domestic and livestock use not served by a water utility.

Self-supplied industrial: Water use that is not obtained from a public supply; mainly electric utility thermoelectric plants.

(ADAPTED FROM MURRAY AND REEVES, 1977)

Water use patterns show a heavy concentration of use for irrigation agriculture in the West. The two western states have over 4 million irrigated acres while Illinois has approximately 68,000 acres, MURRAY & REEVES (1977). The major water use in Illinois is for power generation. Other important uses include manufacturing and municipal use.

The impact of the variance in use patterns can be seen by examining the consumptive rate in each sector. Consumptive use of water in any production process is the portion of total water required which is consumed in the production process and is not available for future production. Since this water is withdrawn from all possible future uses it is an important measure of water use.

Table 5 gives the percent consumed in agriculture as 57.7%, while the percent consumed in power generation is 1.4%.

Table 5

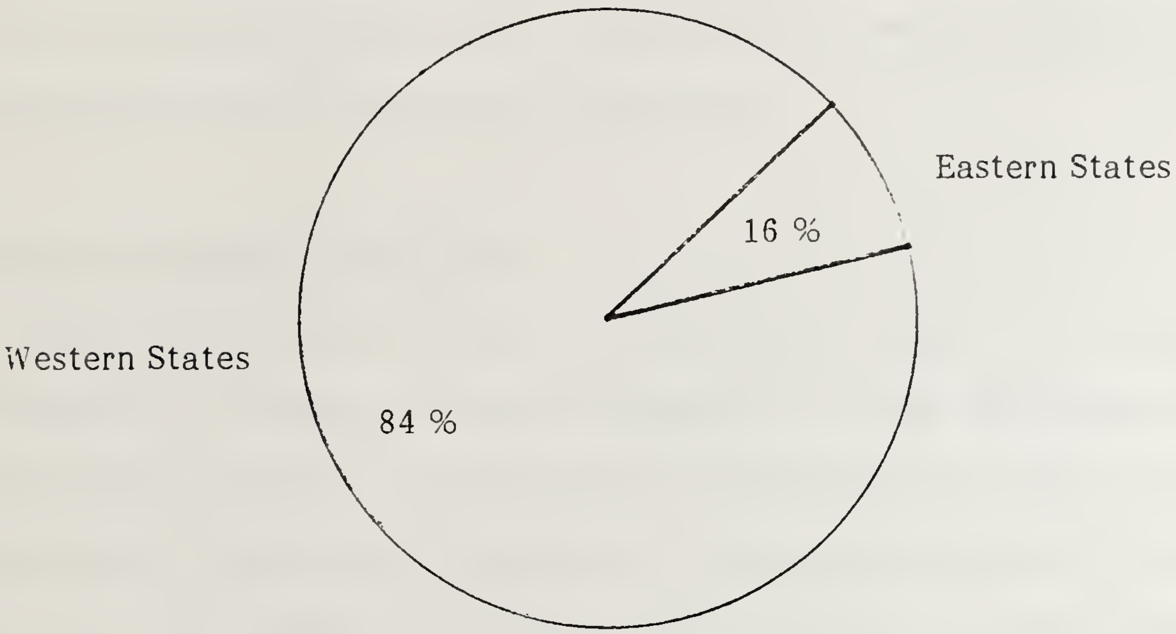
Percent of Water Consumed
by Major Water Users

	Mining & Manufacturing	Power	Municipal	Agriculture
U.S.	11.1	1.4	23.0	57.5

(Adapted from HARTE AND EL-GASSEIR, 1978)

In irrigation, water is contaminated by pesticides and fertilizers. Thus, the potential amount available for reuse is less than half of the water withdrawn in this sector. This explains the high rate of consumption in the West. Geographically, 84 percent of fresh water is consumed in the 17 western states and only 16 percent is consumed in the 34 eastern states. Figure 3 compares fresh water consumed in 17 western states with that in 34 eastern states.

Figure 3. Percent of Water Consumed in 17 Western States and 31 Eastern States



(MURRAY AND REEVES, 1977)

The continued withdrawal of water for irrigation promises increasing water resource problems in the West for several reasons. First, consumption of a large percentage of water in any region may cause serious damage to the quality of the remaining water. The flow and volume of the remaining water may be insufficient for the dilution of any contaminants that would be harmlessly dispersed if sufficient volume had been maintained. Thus, the remaining water may become highly contaminated and inappropriate for even non-withdrawal uses. Second, the low volume of the remaining water may make it useless for even those uses which have no quality-of-water constraints. Third, the fact that the agricultural sector in the West relies heavily on the use of irrigation for its crop production presents an important social dilemma. The diversion of water from this sector could severely cripple the agriculture industry in the West. Many other investigators have shared the same view, e.g., TRELEASE (1976), WILLIAMS (1976), HARTE AND EL-GASSEIR (1978) and HANSEN (1976).

It is clear that the current water use patterns in the West, from the point of view of withdrawal and consumptive use, could seriously constrain the development of coal conversion facilities in that region. In the Midwest a more stable supply to demand relationship exists. This relationship is enhanced by the relatively small amount of consumptive water use in that region.

LAWS GOVERNING WATER USE

As the quantitative estimate of availability and cost of water is important in evaluating the adequacy of water resources for energy development so is the institutional framework of rights and laws governing its use. Most water laws are established for the purpose of insuring the water users a dependable future supply that will assure continuance of use and foster plans for the future based on this dependable supply. Any legal or institutional barriers to the use of water for coal development will have to be identified. Factors in the legal structure that will restrict availability and use will be examined.

Two different legal structures exist in the West and the East as a result of the generally abundant water resources in the East and the mostly arid conditions in the West. Water management in the East will be reviewed and from that understanding the necessity for a different set of standards in the West will become clear.

The early development of U.S. water laws was based heavily on the common law principle of riparian rights from the English. Water in the East was relatively abundant and a complex legal structure was not necessary. The principle of riparian rights was adopted not to allocate water use but to settle the few disputes that may arise between users of an abundant supply.

Water laws in Illinois, strongly influenced by common law rulings, are governed by the doctrine of riparian rights. That is, water rights are recognized as vested property rights. The riparian law gives each owner of land bordering a body of water a right to make reasonable use of the water. Each riparian owner has an equal right to the water. The right exists even if the water is not used and a use may be initiated at any time.

The only restriction on the use of water is that the riparian owner make a reasonable use of the water. Reasonableness depends mainly on the effect the use will have on the quantity and quality of water for other riparian owners. The use should not cause harm to the reasonable uses of others, and, in fact, the use should be in a manner that will accommodate as many uses as possible.

Use of ground water in Illinois, except well-defined underground streams which are subject to the laws governing surface water, is considered a property right of the landowner. The Illinois courts have ruled that landowners can use the water under their property in the quantity and for the reasons they see fit, even though this use will deprive others of their supply. The owner is legally prohibited from maliciously depleting or unlawfully polluting the ground water, CRIBBETT (1958).

Riparian doctrine which suited the eastern states was not sufficient for western states where arid conditions necessitated an allocation of water use among many competing users. The prior appropriation doctrine places emphasis on the distribution of scarce water. The rule of priority insures that those who have obtained water rights will be able to continue their use and new users will not displace them.

Under the prior appropriation doctrine, water users are allowed the use of a specific quantity of water for a specific beneficial purpose. This law is based on

the principle of "first in time, first in right." When periods of insufficient water exist, the appropriators with the earliest claims are entitled to receive their full quantity of water before the appropriators junior to them are entitled to any water. Under the principles of prior appropriation, water is fixed in quantity and based on priority of use.

This method of distribution settles disputes that may occur when western streams are insufficient for all appropriators. The appropriation doctrine is particularly suited for the water-short areas in the West where there is substantial fluctuation in stream flow. The appropriation doctrine recognizes the fact that as demands for water increase, the water rights to supply them will be appropriated until the water is exhausted. Thus, new demands will have to be met with purchased rights.

In relation to coal conversion, the prior appropriation doctrine presents several problems. Water rights have been almost completely appropriated in some areas. In order to develop coal conversion facilities water rights will have to be purchased. The largest number of water rights in many states in the West is for irrigation agriculture. In addition, most senior rights belong to the agricultural sector for irrigation. Water rights can be transferred from one use to another only if the new water use does not harm other water users. Where water needs for energy will mean acquisition and transfer from the agricultural sector, serious problems are likely to arise.

In areas where new rights can be obtained, the coal conversion industry will be the junior appropriator which means that in periods of low flow, water may be unavailable. The coal conversion industry relies on a dependable supply of water for its operation.

There are other legal and institutional factors which may limit or constrain the availability of water for coal conversion. For example, the federal government and some Indian tribes are making claims on western water rights. The U.S. government believes that ownership of all water within the public domain lands of the U.S. resides with the federal government and that the government therefore has the right to reserve for its use any water that has not been previously appropriated. Indian tribes assert that water in or adjacent to tribal reservations is the property of the Indian tribe. The GENERAL ACCOUNTING OFFICE (1978) reports that it is now nearly impossible for the states or the potential water users to determine if water is available for new users or if current water users will be superceded by the exercise of federal and Indian reserved rights. It cannot be determined how much water is available for energy development in this area until the federal government and the various Indian tribes officially claim their water rights, see WILLIAMS (1976) and HANSEN (1976).

In addition, the western states have interstate compacts which limit out-of-basin diversion. The Yellowstone River Compact is a case in point. About one-half of Wyoming's strippable coal lies within the Yellowstone River Basin and the remaining coal lies outside the Basin. The Compact requires the unanimous consent of the three participating states, Wyoming, Montana and North Dakota, to divert water from the Yellowstone River Basin area. Consent is expected to be very difficult to obtain, see WILLIAMS (1976), U.S. BUREAU OF LAND MANAGEMENT (1978) and TRELEASE (1976).

There is also environmental opposition to the development of new dams, reservoirs or pipelines. The agricultural interests oppose any proposal that would entail the transfer of irrigation rights. Recent water shortages in the West have

meant that almost any proposal that calls for the acquisition of large amounts of water will not be without opposition and adversaries.

It is clear that competition exists in many areas of the West for use of available water especially in periods of low flow (see Table 3) even before the demands of the energy industry. These conflicts have been adequately resolved using the existing legal structure. However, with the onset of water demands for coal conversion the ability of existing structures to resolve conflict is questionable.

A number of factors have caused increasing concern over the ability of existing water laws in the West to cope with the problems of water allocation. These factors include increasing population, periods of localized drought conditions and lowering of water tables, and expanding use of water for supplemental irrigation and municipal, industrial, recreational, and other uses.

RESOURCE COST OF WATER

The unique characteristics of water makes its worth difficult to determine. The value of water is the value of the marginal product in the first use, plus the marginal product in the second use and so on. The imputation of the resource cost of water is an enormously complex task. This is so because water resources consist of both a stock and a flow component and they suffer from the problem of common property resource. Besides, imputing the resource cost of water would require estimates of the amount of ground water and surface water which can be economically exploited, knowledge of the hydrologic and economic feasibility of diverting water resources from one point to another, and consideration of the appropriate discount rate and expected technological changes including finding substitutes for water in the different uses. Another method, the residual imputation method of determining the value of water in a production process,

subtracts the value of all other resources from the total value of the production. The remainder is the value of water. But, assigning values for all other resources, including return to entrepreneur, is very difficult.

Recognizing the difficulty in imputing the resource cost of water, the following simplifying assumptions are made: (1) the resource cost (opportunity cost) of water can only be measured when it has been determined that coal conversion in a given region will necessitate the transfer of water from another water-using sector; (2) the transfer will most likely divert water from the highest water-using sector; and (3) average value product of water, in the sector from which water may be diverted for coal conversion, is a measure of the resource cost. With these assumptions the average value product of water is computed by dividing the gross revenue from the production process by the amount of water required and consumed in its production.

Both consumptive use of water and total water requirements of a production process are used to yield two separate estimates of the water productivity in Table 6.

Table 6

Average Value Product of Water ($/Acre-foot)

Use and Region	Average Value Product of Water: Required Usage	Average Value Product of Water: Consumptive Usage (1)
Agriculture (West)	15.30 (2)	26.61
Power Generation (Midwest)	87.64 (3)	8,764.00
Coal Liquefaction (U.S.)	22,345.00 (4)	28,647.00

[1] Obtained by dividing Column 2 by percent of water consumed from Table 5. Percent consumed in coal conversion is approximately 78% as given by BRILL, et al. (1977b).

[2] Value of the total output of irrigated acreage for the states of Wyoming and Montana given respectively by D. J. BROSZ (Irrigation Engineer, University of Wyoming, personal communication) and G. FRITZ (Planning Bureau Chief, Montana Department of Natural Resources and Conservation, personal communication). This value was divided by the total water used in Montana and Wyoming for irrigation from MURRAY AND REEVES (1977).

[3] Obtained by dividing total revenues from power sales in the Illinois Region given by EDISON ELECTRIC INSTITUTE (1976) by total water requirements for power generation estimated by MURRAY AND REEVES (1977).

[4] Assumes a plant producing 100,000 bbl/day of synthetic crude oil from coal 330 days a year. The revenue was calculated using a price of $14.52 per barrel given by the U.S. DEPARTMENT OF ENERGY (1979). The revenue obtained above was then divided by water requirements for the plant as estimated by PARSONS (1974). The price of $14.52 is the composite acquisition cost of crude oil for April 1979.

The average value product per acre foot of water in agriculture in the West is $15.30 per acre foot. This estimate is a measure of the worth or value of the input (water) to the productive process. The productivity of water in irrigation agriculture depends on environmental conditions, the use of other inputs such as fertilizer and capital investment, and the type of product being produced. Similar results have been obtained from other researchers. For example, HANSEN (1970) and the WESTERN STATES WATER COUNCIL (1977) both estimated the return to water in agriculture to be close to $20 per acre foot while HARTMAN AND SEASTONE (1977) estimated it at $36 per acre foot.

The average value product for power generation in Illinois is also included in the table. Power generation is the major water using sector in the region. The average value product for power generation is not the resource cost, unless it has been determined that water for coal conversion will be diverted from another water-using sector.

In the Midwest a more favorable supply to demand relationship exists due to the humid conditions and the relatively lower rate of consumptive use. Since water resources are relatively plentiful, it is unlikely that water for coal conversion will have to be diverted from any water-using sector in the near future. Consequently, the resource cost of water in the Midwest is estimated to be negligible. Localized shortages, of course, could occur as the availability of water for coal conversion

purposes depends greatly on the specific location within Illinois where facilities are sited. Competition for available water resources is also more likely to be stronger in some areas than in others. And, assigning a resource cost of zero to water resources in the Midwest probably reflects the unavailability of the proper data. The resource cost of water in the Midwest could be calculated by computing the economic losses imposed on the recreation industry or water transport industry because of lowering of water levels in navigable rivers, see WALKER AND COX (1974). However, no information is available to make any quantitative estimates.

The average value product for coal liquefaction is $22,345.00 per acre foot. The magnitude of this number attests to the high economic value of energy. Even using water use estimates 6 times those used here results in an average value product of $3,724.00 per acre foot. This is substantially greater than the return to either agriculture or power generation.

As stated in assumption (1) when water is directed for use in coal conversion it will be directed from the largest water-using sector. In the West, this is the agricultural sector where 95% of the water is distributed for this purpose. Much of the water available in the West has already been appropriated and therefore supplies for coal conversion would be obtained, to a certain extent, through sales and transfers of water rights from existing uses, principally agriculture. Water use in other sectors is a comparatively minor use of water. If it were established during siting procedures that water would be diverted from one or more of these sectors, resource costs incurred could be calculated using methods similar to those presented here.

The resource cost in the West for each acre foot of water is $15.30. This represents the productivity that would have been gained if agriculture had retained use of the water. The productivity lost in this sector becomes a cost to the coal

sector because the transfer of water has eliminated the productive ability of the agriculture sector. This conclusion does not take into account the possibility and productivity of dryland farming. Dryland farming accounts for a small fraction of the productivity in this arid region. However, a complete examination of the resource cost of water would include the alternative uses of the acreage under water transfer conditions.

IMPLICATIONS OF RESOURCE COST IN THE WEST

The decision to encourage and develop coal conversion facilities in one region over another must take into account the resource cost (opportunity cost) of water in each region. It has been determined that the resource cost of water will be between $15.30 and $26.61 per acre foot in the West and zero in the Midwest. This cost can be put in perspective by examining the effect on the cost of coal conversion, the effect on the agricultural sector and the likely changes in gross product (income) in the West as a result of the reallocation of water.

All other factors remaining constant, the cost of producing a barrel of synthetic crude from coal in the West would be higher than in the Midwest by an amount equal to the resource cost of water. This cost represents the foregone outputs that could have been obtained from the alternative employment of resources used. It should be emphasized that the resource cost of water does not include the cost of making water available (pumping, extraction, etc.) and is only a very small part of the total cost of producing synthetic crude.

Multiplying the total water requirement per barrel of synthetic crude by the average value product of water in agriculture yields a resource cost of water of less than one cent per barrel of synthetic crude in the West.[2]

The actual water requirements of coal conversion depend on a multitude of factors such as the kind of synthetic product being produced, technology used, method of cooling and coal characteristics. The highest estimate of water use for coal conversion is approximately six times the estimate used for these calculations. Using this estimate the resource cost of water is six cents per barrel. The resource cost of one 100,000 bbl/day plant producing 33 million bbl/year would be between $330,000 and $1,980,000 depending on water use (see Table 7).

Suppose 10% of the current annual U.S. oil consumption, or 700 million barrels, was produced by coal conversion facilities in the West. This would mean approximately 21 plants producing 33 million barrels per year using 450,324 acre feet of water (21,444 times 21). The resource cost of diverting 450,324 acre feet of water would be $7 million (700M x .01). Using water requirements 6 times this estimate yields a cost of $42 million (700M x .06).

It could be argued that a resource cost of $7 million or $42 million to an industry producing 10% of U.S. oil consumption is an insignificant amount. In the energy industry, costs are passed on to the consumer in the form of higher prices, so that the brunt of the resource cost will not fall on the industry but on the consumer. In this case the costs also must be borne by society as there is a cost involved in the displacement of a portion of the agricultural industry.

The 450,324 acre feet of water needed to produce 700 million barrels of oil from coal is approximately equal to the water necessary to irrigate 2.3% of the farms in the two western states. If 2.3% of the farms were without water for irrigation, there would be 395 displaced farms affecting 1,370,255 acres. When the highest estimate of water requirements is used the number of displaced farms is 6 times the amount or 2,370 farms comprising 13.8% of the total and affecting 8,221,530 acres.[3]

Thus, the production of 10% of U.S. oil consumption could have a resource cost of between $7 million and $42 million and could displace between 395 and

2,370 farms. Gross product in the region could go up by $10,164 million (700 million bbls of oil x $14.52, the most current price for oil available at this time) from the production of synthetic fuel. Revenues in the region will be reduced by the income foregone in irrigated agriculture. Land values would be reduced to the value of the alternative use of the land. Currently, the average value per acre of land is $96. The total value of the affected acreage is between $131 million and $789 million depending on water use.[4]

Table 7

Water Use and Cost Statistics

	Most Likely Estimate	High Estimate (approximately 6 X likely estimate)
Water Requirement for 1-100,000 bbl/day plant (33M bbl/year)	21,444 AF/yr.	130,000 AF/yr.
Water Requirement for 21 plants producing 10% of U.S. consumption of crude (700M bbl/year)	450,324 AF/yr.	2,730,000 AF/yr.
Water Requirement for bbl of synthetic crude	.00065 AF/yr.	.004 AF/yr.
Resource Cost of Water per bbl of crude	$.01	$.06
Resource Cost per plant per year (33M bbl/year)	$330,000	$1,980,000
Resource Cost for 21 plants (700M bbl/year)	$7M	$42M
% of farms displaced if water is diverted from agriculture and 700M bbl/year of crude are produced	2.3%	13.8%
Number of farms displaced if water is diverted from agriculture and 700M bbl/year of crude is produced	395	2370
Acres of agricultural land affected by displacement of farms	1,370,255	8,221,530
Total value of affected acreage (multiply affected acreage by $96)	$131,544,480	$789,266,880

FACILITY SITING LITERATURE

To our knowledge the methodology developed here to measure the resource cost of water has not been applied in identifying sites available in Illinois for coal conversion. Previous studies that have examined the water-related needs in energy production have been generally limited to the availability of water supply given a particular demand for water. Usually, the studies have endeavored to locate areas of excess water supply of approximately 20,000 acre feet per year to accommodate large-scale coal conversion facilities. Excess supply is defined as available supply minus existing or potential demand for water resources.

The researchers have found that several of Illinois' major rivers are suitably located near coal mines and contain adequate uncommitted reserves of water, thus providing economical, desirable locations for coal conversion facilities. The Kaskaskia, the Big Muddy, the Illinois and the Sangamon River, are suited for economical coal development processes and contain an excess supply of water. Three reservoirs: Lake Shelbyville, Carlyle Reservoir and Rend Lake were named as potential sites. The Mississippi, the Wabash and the Rock River, could provide water to coal conversion facilities in sufficient quantities but water would have to be economically transported to the coal areas. Several of these studies in Illinois are summarized below.

"Issues Related to Water Allocation in the Lower Ohio River Basin," BRILL, et al. (1977b) includes runoff and inflow estimates for the State. Water consumption figures were calculated and presented as a percent of stream flow. Consumptive use of water was re-computed under various scenarios that called for additional power plant implementation. The report found that the Illinois River and the Mississippi River continued to have low consumptive ratios even with extensive power plant development but the Kaskaskia and the Big Muddy would have much higher consumptive ratios.

"Water for Energy Self-Sufficiency," U.S. WATER RESOURCES COUNCIL (1974) analyzed water resources for potential energy development on a regional basis. The report presented estimates of supply and demand in addition to institutional constraints beyond availability that might restrict use of water for energy in a region. Total water supply in the region that encompasses Illinois was estimated to be 68,000 mgd. Water withdrawal in the region is projected to be between 15,000 mgd and 29,000 mgd by 1980. Consumptive use of water is estimated to be 10% of withdrawal.

"Potential Sites for Coal Conversion Facilities in Illinois," HOGLUND AND ASHBURY (1974) located areas that have an excess supply of water for coal development. An excess supply of water was defined as expected supply minus expected demand. The report found only three counties in the State that did not have excess supply of over 13,000 acre feet.

The Chicago Institute of Gas Technology, SEAY et al. (1972) identified surface water supplies adequate to support coal conversion plants requiring between 16,130 and 32,260 acre feet per year. Water supply and withdrawal in each county was assessed. Sites were evaluated based on the amount of excess supply available to a coal conversion facility and the cost of water pipeline and storage reservoirs. The study reported that there are sufficient water resources in each of the 12 Illinois counties determined to be otherwise suitable locations for coal development. Another siting report by SMITH AND STALL (1975) located more than 200 sites in Illinois that could supply between 16,000 and 80,000 acre feet per year.

The information presented in these reports is necessary in siting coal conversion plants in Illinois. However, there is a need to go beyond calculations of excess supply. This report addresses the issue of productivity and opportunity costs of water.

Currently, numerous locations are being considered as potential coal conversion facility sites. Where water is available and no diversion is currently required, consideration should be given to future constraints. The sector from which water will most likely be diverted and the resource cost of diversion can be computed for a future date. Where consideration is given to several plant sites that will result in the diversion of water from a current use, the resource cost should be computed in order to access the desirability of the alternative locations.

Future siting studies can utilize this methodology in analyzing potential locations for coal conversion facilities. The process could be similar to the work presented here. First, supply and demand for water resources in the area should be computed. Second, estimates of consumptive use of water will play a key role in determining if water will be available and if water levels will be sufficient during periods of low flow. Third, a review of the legal and institutional constraints on the use of water should be completed. Fourth, in the event of a potential shortfall in water resources in either the near or long term, opportunity cost should be computed and included in cost benefit analysis.

As discussed earlier, water requirements for coal conversion depend on the technology employed. When siting and designing coal conversion facilities, the most efficient level of water use will be based, in part, on the supply and demand for water. Extensive use of water in a facility may be more economical than expensive air cooling equipment when abundant water resources exist. Conversely, where heavy use of water will entail a relatively large monetary cost or resource cost, the trade-off may favor more technology and less water.

CONCLUSION

The availability of a sufficient water supply is an integral component of future coal conversion technologies. An abundant, dependable supply of water is

necessary for mining, transportation, conversion and use of coal in most coal development projects. Beyond the availability of sufficient quantities of water in a given region to meet coal conversion needs, there are questions of water quality, institutional barriers, legal and economic problems, as well as concern from current users.

Several major conclusions surface from this investigation. First, there is a comparatively larger supply of water available in the Midwest than in the West. This is evident from the water supply and demand data in both regions. This is not to say that excess supply does not exist in the West nor does it prove that water is necessarily available for coal conversion in the Midwest. Availability of water for a coal conversion facility in either region is dependent upon the localized conditions at a specific site. However, the water supply to demand relationship in the Midwest is more stable than in the West. Further, gross figures on water availability are substantially larger in the Midwest. Also, the large consumptive requirement in the West, coupled with seasonal variations, poses a problem relative to water availability. A comparatively smaller amount of water has the potential for reuse in the West due to the contaminents in irrigated water. During periods of low flow, additional water is needed for agricultural production, increasing the amount of water required and consumed.

Second, legal and institutional constraints in the West could limit the amount, location and use of water for coal development. Water resources which have sufficient capability for coal conversion are protected by a complex series of interstate compacts, appropriation claims, and federal and state statutes. Competition exists in many areas for use of available water even before the demands of the energy industry. These conflicts have been adequately resolved using the existing legal structure. However, with the onset of water demands for coal conversion the ability of existing structures to resolve conflict is questionable.

Third, the resource cost of water, as computed in this report, should be considered in making decisions on the location and pace of coal conversion. Large scale coal conversion in the West could displace a potentially large portion of the agricultural sector. Using the assumptions in this report, coal conversion facilities could displace from 2% to 14% of western farms. The economic and social costs of this water transfer should be recognized and fully evaluated.

Fourth, a review of the facility siting literature reveals a need to go beyond estimates of supply and demand of water. The methodology developed in this report should be useful in siting coal conversion facilities in the future. Although the opportunity cost of water, as computed in this report, was for a whole region, it is believed that this method is valid and applicable to the siting of facilities in a local area. The imputation of the resource cost of water should be an important element of facility siting decisions.

This report should not be interpreted to imply that coal conversion will necessarily be cheaper in the Midwest than in the West or that coal conversion should be encouraged in one region over another. Only a thorough cost benefit analysis including social costs and benefits can address that question.

The report is an assessment of the availability, use, and cost of water resources in the West and Midwest. Decisions to develop coal conversion technology, the pace of that development and the location of conversion facilities should be based not only on information on the resource cost of water but also on such other factors as the availability of coal, the proximity to market of coal derivatives and other environmental considerations.

Footnotes

[1] Water supply and demand will be presented in quantities of million gallons per day while the water requirements for coal conversion facilities is described in acre-feet per year. One million gallons of water per day (mgd) is equal to 1,120 acre feet per year (AF/YR.) so that 53,000 mgd can be converted to 59,360,000 AF/YR.

[2] 100,000 bbl/day for 330 days is 33M bbl/year. Water use per year (21,444 acre feet) divided by barrels produced per year (33M) is .00065, the amount of water required for each barrel of synthetic crude. Water per barrel (.00065) times resource cost per acre foot ($15.30) is .01, the resource cost per barrel.

[3] 450,324 acre feet divided by 19.6 million acre feet (water use for irrigation agriculture in Montana and Wyoming) is 2.3% and 2.3% of 17,151 irrigated farms is 395 farms. (BUREAU OF THE CENSUS, 1977) Average acreage per farm (3,469) multiplied by number of farms displaced (395) is 1,370,255. To calculate displaced farms and affected acreage using the highest estimate of water, multiply by 6.

[4] Average value of acres ($96) times 1,370,255 affected acres equals $131,544,480. Highest estimate of water use would affect 8,221,530 acres at a total value of $789,266,880 (8,221,530 times $96). (BUREAU OF THE CENSUS, 1977)

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